



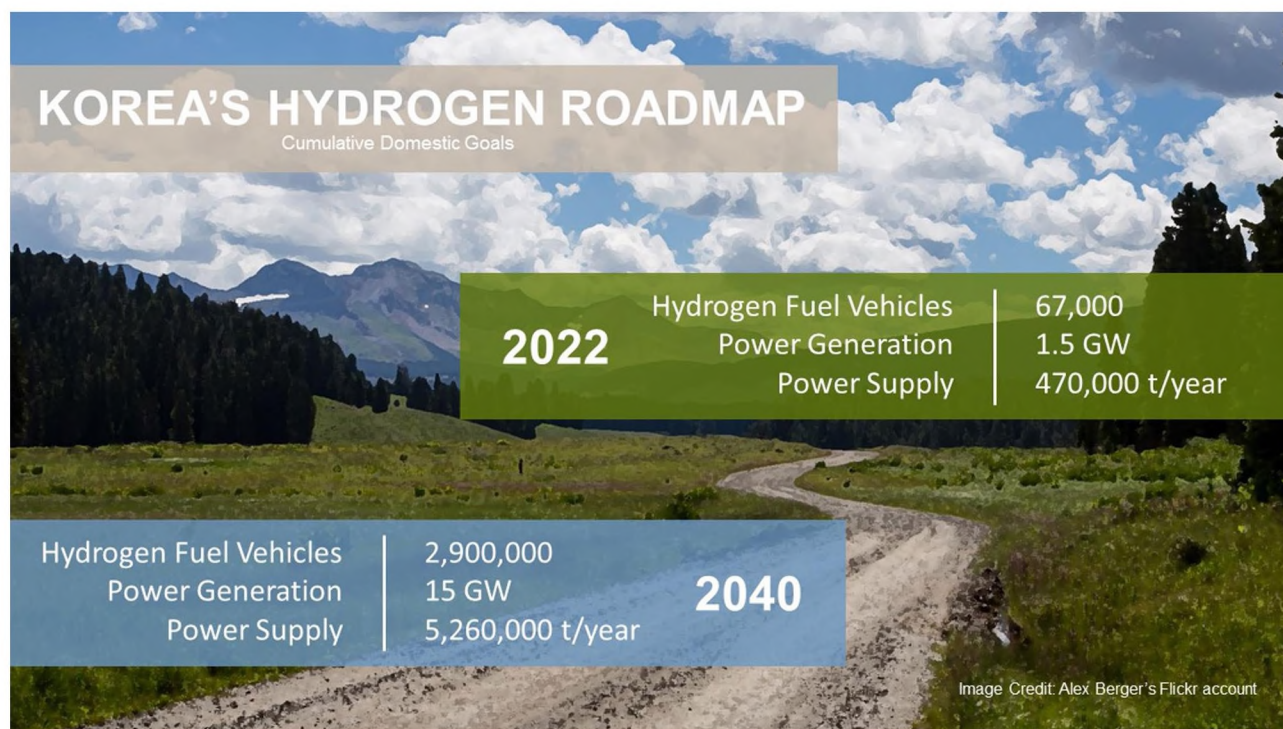
# South Korean efforts to transition to a hydrogen economy

Troy Stangarone<sup>1</sup> Received: 31 March 2020 / Accepted: 27 August 2020  
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## Abstract

As the world increasingly looks to renewable energy sources to deal with climate change, South Korea is aiming to become a leader in the development of hydrogen as an alternative energy source. In developing an ecosystem for a hydrogen economy, South Korea is focused on increasing the production and use of hydrogen vehicles, establishing an ecosystem for the production and distribution of hydrogen and related technologies, and expanding the production of fuel cells. The government's vision has the backing of key industrial firms, most importantly the Hyundai Motors Group which plans on investing 7.6 trillion won (\$6.7 billion) under its "FCEV Vision 2030" and is part of the HyNet consortium to build 100 new hydrogen refueling stations in South Korea by 2022. If South Korea's vision is successful, it expects hydrogen to account for 5% of its projected power consumption in 2040, to see its economy grow by 43 trillion won, 420,000 new jobs created, and significant reductions in both fine dust and greenhouse gas emission.

## Graphic abstract

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ts@keia.org

Extended author information available on the last page of the article

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As the world increasingly looks to renewable energy sources to deal with climate change, South Korea is aiming to become a leader in the development of the hydrogen economy. The vision laid out by South Korean President Moon Jae-in calls for South Korea to focus on increasing the production and use of hydrogen vehicles, establishing an ecosystem for the production and distribution of hydrogen and related technologies, and expanding the production of fuel cells.

While the Hydrogen Economy Roadmap developed by the Moon administration covers different components of developing a hydrogen-based economy, much of the plan will rest on South Korea's ability to expand the acceptance of fuel cell electric vehicles (FCEVs) first in South Korea's domestic market and in time in markets around the world.

However, if South Korea is successful in developing hydrogen as more than a niche energy source domestically, its success could serve as a demonstration of the technology's viability and offer insights into the best means of transitioning to a hydrogen-based economy.

## Why South Korea is pursuing a hydrogen-based economy

As South Korea and the international community work to decarbonize energy, hydrogen is increasingly viewed as a promising alternative that can address South Korean concerns related to the environment, energy security, and economic growth.

While South Korea does have offshore wind potential (International Energy Agency 2019), its onshore wind and solar potential are more limited (ESMAP 2020). While green hydrogen can be produced with renewable energy, the ability to utilize gray hydrogen produced from gasoline, biomass, methane, and other sources gives it more flexibility even with varying degrees of pollution depending on the fossil fuel used to produce the hydrogen (Hydrogen Energy Center).

Hydrogen is also becoming more economically viable as an energy source. The Hydrogen Council estimates that hydrogen will become increasingly competitive over the coming decade as prices fall by 50% and it expects that hydrogen will become the renewable energy of choice in areas such as industrial heating and long and heavy-duty trucking (Hydrogen Council 2020).

The flexibility of hydrogen fuel cells provides other advantages. McKinsey & Company estimates that hydrogen can play a role in transforming the world's energy infrastructure in a series of areas: long-term energy storage, the distribution of energy, energy resilience, cleaner feedstock for chemicals, and decarbonizing the transport, industrial, and building sectors (Heid 2017).

In the transport sector, hydrogen also has certain advantages over electric and gasoline vehicles. As an energy source, hydrogen has a higher density of energy than gasoline. While electric vehicles still trail gasoline-powered vehicles in driving range, hydrogen vehicles can be built with a comparable driving range to gasoline vehicles (Malloy 2019). Advances could further reduce constraints on hydrogen vehicles with recent research on the development of a manganese hydride molecular sieve that would reduce both the cost and weight of hydrogen systems (Morris et al. 2019). Hydrogen vehicles can also be refueled 15 times faster than the charge time for fast charging stations, the stations take up less space than electric charging stations, and they are also less intensive on natural resources (Heid 2019).

South Korea's decision to invest in developing a hydrogen-based economy also aligns with domestic needs. In announcing South Korea's hydrogen economy roadmap, President Moon Jae-in laid out three reasons for pursuing a hydrogen-based economy—economic growth, energy security, and the environment (Cheong Wa Dae 2019a, b).

## Economic growth

With the world's lowest total fertility rate, South Korea's population is aging more quickly than other developed countries, including Japan. One consequence of the decline in fertility and an aging population is the slowing of South Korea's economic growth potential (Stangarone 2020b).

To address concerns about a slowing economy and increasing competition from rising developing countries such as China, the South Korean government is investing in promising emerging technologies to foster a series of new engines for economic growth that will help keep the economy competitive and spur job creation. In addition to industries related to the utilization of hydrogen as a fuel source, South Korea has identified 5G, artificial intelligence (Song 2019), system semiconductors, biotechnology, and autonomous vehicles as other promising industries to foster (Cheong Wa Dae 2019a, b).

If South Korea is able to achieve the objectives laid out in its Hydrogen Economy Roadmap, it would make South Korea a leader in a new renewable energy field and a growing industrial segment. The South Korean government estimates that this would add 43 trillion won to the economy and create 420,000 new jobs by 2040.

## Energy security

With only trace amounts of fossil fuel deposits, South Korea is dependent on imports for 98% of its fossil fuel needs. South Korea's power generation largely consists of fossil fuels and nuclear power, with petroleum accounting for 44% of energy consumption. In the case of petroleum,

South Korea has historically been reliant on imports from the Middle East with the region accounting for 81% of South Korea's petroleum imports in 2017 (U.S. Energy Information Agency 2018).

Nuclear power accounts for 22% of South Korea's power generation and 11% of consumption, but with no domestic supplies of uranium South Korea is also dependent imports for nuclear fuel (World Nuclear Association 2019).

The South Korean government estimates that hydrogen could account for 5% of its expected energy consumption in 2040, if the objectives in its roadmap are achieved.

### Environmental factors

South Korea is one of the world's largest emitters of greenhouse gases on a per capita basis. In 2018, South Korea's emissions of CO<sub>2</sub> reached 624 MT and 12.1 T per capita according to the International Energy Agency. In South Korea's Paris Climate Accord submission, it pledged to reduce emissions by 37% from its 2030 business as usual baseline which was estimated to be 850.6 metric tons. To meet these goals, it will need to increase its use of renewable energy.

Air pollution has also become a growing public concern in South Korea. Hazardous air pollution, often associated with developing countries, has become more common. In 2017, South Korea saw a significant increase in the number of days that required ultra-fine dust (PM<sub>2.5</sub>) warnings (Harris and Kang 2017). The most recent summary of the Joint Research Project for Long-range Transboundary Air Pollutants in Northeast Asia commissioned by South Korea, China, and Japan found on average in 2017 that 51.2% of PM<sub>2.5</sub> in major South Korea cities was domestic in origin, while 32.1% came from China (National Institute of Environmental Research 2019).

The growth in air pollution has public health consequences for South Korea. According to the University of Chicago's Air Quality Life Index, the average South Korean can expect their life expectancy to decrease by 1.4 years with a more significant decline for those living in Seoul (Energy Policy Institute at the University of Chicago 2019). Additionally, the Organization for Economic Cooperation and Development (OECD) projects that South Korea will be among the countries with the most significant increase in number of premature deaths among OECD members by 2060 (Organization for Economic Cooperation and Development 2016).

The issue of air pollution is also gaining political salience. It was a prominent political issue in the 2017 presidential elections (Fifield 2017), and the continuing challenges South Korea faces from air pollution remain one of the most significant reasons voters say that they disapprove of the policies of President Moon. Those in their 20s and 30s

are most likely to list fine dust as a reason to disapprove of President Moon's policies, but more broadly 81% of South Koreans are concerned about the levels of PM<sub>2.5</sub> in South Korea (Gallup Korea 2019).

Hydrogen is part of the South Korean government's plan for addressing greenhouse gas emissions and ultra-fine dust. The South Korean government estimates that if its targets for hydrogen vehicles are met, it could reduce fine dust by 2373 metric tons a year and greenhouse gas emissions by 27.28 million metric tons in 2040. In terms of fine dust, the closure over time of coal-based plants would have a significant impact if South Korea took stronger measures to reduce its usage of coal. In late 2019, South Korea temporarily cut generation from coal plants to 80% of capacity and saw fine dust decline by 46% (Yonhap News Agency 2019).

### South Korea's hydrogen economy roadmap

In 2019, South Korea published a roadmap for promoting a hydrogen-based economy that focuses on the transportation sector, decarbonizing industry and buildings, and managing the production and distribution of hydrogen. The roadmap and subsequent legislation passed by the National Assembly are designed to provide objectives, outlines for industry support, and a legal foundation for South Korea's efforts to pursue the development of hydrogen as a fuel source.

At the center of South Korea's strategy is an effort to "prime the pump to create a bigger market" for hydrogen and provide the support needed at this early stage for the private sector to grow the market for hydrogen in the long-term and reach the economies of scale to reduce prices (Cheong Wa Dae 2019a, b). In addition to providing support to the private sector in the form of subsidies for hydrogen projects, R&D, and regulatory reform, South Korea is working to develop and demonstrate the viability of hydrogen fuel cells. As part of its demonstration efforts, South Korea plans to establish three hydrogen demonstration cities by 2022. These cities would use hydrogen for transportation, electricity, heating, and cooling, while serving as an initial step in transitioning 30% of South Korea's cities to hydrogen by 2040 (Edmond 2019).

### Transportation and construction industry

The roadmap places significant emphasis on the transportation sector. Despite efforts to reduce greenhouse gas emissions, vehicles with combustion engines still dominate the global market. Global sales of electric vehicles, the leading alternative to the combustion engine, only amounted to 2.1 million units in 2018 and just 2.2% of all vehicles sold (Hertzke 2019). Hydrogen vehicles account for a much small part of the market with sales of only about 7500 vehicles in

2019 (Kane 2020a). However, the South Korean government estimates that if just 10% of the global automobile market shifts to hydrogen, the new market for hydrogen vehicles would be worth around \$125 billion.

Despite the current low sales volume for hydrogen vehicles, South Korea hopes to expand domestic production of hydrogen FCEVs to 35,000 units by 2022 and 65,000 hydrogen FCEVs on South Korean roads. By 2025, it has targeted production of 100,000 units with 40,000 units for export. It also estimates that at volumes of 100,000 units the price of hydrogen vehicles would be competitive with internal combustion engine vehicles (Government of Korea 2019). By 2030, hydrogen and electric vehicles are expected to make up a third of all new cars sold domestically (Kang 2020b).

To encourage the sale of hydrogen vehicles domestically, South Korea's roadmap calls for subsidizing the purchase price of vehicles and investing in R&D. Under South Korea's subsidy scheme, the level of subsidy would fall as the price of vehicles declines with increased production. In 2020, South Korea has adjusted its subsidy scheme for eco-friendly vehicles and will provide upwards of 42.5 million won (\$34,715) for the purchase of a hydrogen vehicle (Yonhap News Agency 2020d), while under its current budget, it is set to spend 43.1 billion won in R&D on hydrogen-related technologies in 2020 (Yonhap News Agency 2020e).

In addition to passenger vehicles, South Korea's roadmap also calls for the expansion of hydrogen into other areas of transport. For personal travel, the roadmap calls for the introduction of 80,000 hydrogen taxis and 40,000 hydrogen buses by 2040. It also calls for the introduction of 30,000 hydrogen trucks over the same period for the transportation of freight.

The roadmap also includes steps for research into utilizing hydrogen to power ships, trains, drones, and construction equipment, but these areas are more focused on R&D with the goal of being able to commercialize the technology before 2030.

## Refueling stations

Similar to the adoption of electric vehicles, the lack of refueling stations remains an obstacle to the adoption of hydrogen-powered vehicles more widely. South Korea's roadmap calls for expanding the number of refueling stations from the current 34 stations to 310 in 2022 and 1200 by 2040 (Kang 2020a). South Korea plans on providing subsidies and reducing regulations to encourage the construction of new refueling stations to facilitate this expansion.

Under the government's roadmap, different types of subsidies would be available for different types of installations. In urban areas, the Ministry of Environment would provide subsidies of 50% of the installation cost per station up to 1.5 billion won, while the Ministry of Land, Infrastructure,

and Transport would provide 750 million won per station on highways. South Korea also plans on loosening regulations on the location and approval process for the installation of hydrogen refueling stations, as well as using new provisions for the establishment of a regulatory sandbox to ease installation in the short term.

## Power generation and supply

South Korea currently generates 307.6 MW from fuel cells, but has targeted expanding that production to 15GW by 2040. The expectation in the roadmap is that 8GW would be for domestic use, while 7GW would be dedicated to exports. To foster the production of power through fuel cells, the government would implement an LNG price exclusively for fuel cells and maintain renewable energy certificates (RECs) over a period of time to provide investors with a degree of certainty. It would also provide additional value to RECs for green hydrogen projects and is considering a long-term, fixed price system for power generated from fuel cells.

The roadmap has also set the goal of providing households and other buildings 2.1GW of power from fuel cells by 2040. This market would be grown through a mixture of incentives such as a special electricity tariff and mandatory steps such as the replacement of cooling systems at public institutions with fuel cell systems.

If the demand for hydrogen grows in line with South Korea's hydrogen roadmap, demand for hydrogen would increase from 130,000 tons in 2019 to 5.36 million tons a year in 2040. Currently, South Korea's hydrogen needs are supplied from byproducts in the petrochemical process. As demand grows in the early stages, South Korea would produce hydrogen using LNG. However, in the longer term it is also considering options for producing green hydrogen. These include using surplus renewable energy and hydrogen produced in conjunction with the development of new large-scale renewable energy projects. The roadmap also expects South Korea to begin importing green hydrogen by 2030. To ease the domestic shipment of imported hydrogen, South Korea is considering installing pipelines at the point of import. These and other potential pipeline initiatives would add to South Korea's current 200-km hydrogen pipeline.

The Korea Gas Corporation (KOGAS) has also developed its own hydrogen plan. The state owned KOGAS plans to invest 4.7 trillion won (\$4.06 billion) by 2030 on R&D the construction of 25 hydrogen production facilities and 700 km of new pipeline. With increased domestic production and imports of hydrogen beginning in 2030, KOGAS hopes to bring the domestic price of a kilogram of hydrogen down to 3000 won from its current price of 6500–7500 won by 2040 (Kim and Suh 2019).

## Legal framework

At the beginning of 2020, South Korea's National Assembly passed the Hydrogen Economy Promotion and Hydrogen Safety Management Law. The legislation, the first of its kind internationally, provided the legal framework for the government's efforts, including the subsidies that South Korea is providing to the industry. It also established the "Hydrogen Economy Committee," chaired by the Prime Minister, which will serve as a control tower to oversee issues related to industry promotion, distribution, and safety (Ministry of Trade, Industry, and Energy 2020).

While the legislation provided a legal framework for the government's efforts to develop hydrogen as a fuel source, legislation related to enforcement of ordinances and the enforcement of rules is still needed.

## Other governmental policies related to hydrogen

In response to the economic consequences of COVID-19, South Korea has developed a policy response not to just manage the economic consequences of COVID-19 but also to prepare the economy for the post-COVID period known as the Korean New Deal (Stangarone 2020a).

The Korean New Deal is divided into two planks, the Digital New Deal and the Green New Deal. Under the Green New Deal, the Moon administration aims to accelerate South Korea's transition from a carbon-dependent economy to a low-carbon economy and is committed to spending 42.7 trillion won on green projects by 2025. As part of the Green New Deal, South Korea has set a new target to have 200,000 hydrogen vehicles on the road by 2025 (Government of the Republic of Korea 2020).

The Green New Deal will also expand subsidies for hydrogen vehicles. Hydrogen-powered trucks will be eligible for subsidies from 2021, and subsidies from fuel rechargers for commercial vehicles will become available in 2022. All hydrogen vehicles will be eligible for state subsidies by 2025 (Kim and Kim 2020).

South Korea has also taken other steps to encourage the use of hydrogen. Under its renewable portfolio standards (RPS), South Korea currently generates 7.6% of its power from renewables. The RPS requires producers with a capacity over 500 MW to generate an increasing amount of power from renewable sources, or to purchase RECs, reaching 10% in 2022. The RECs are issued based on the type of renewable power generation with extra weight given to certain technologies based on different environmental and technological considerations. While hydrogen fuel cells have one of the higher weights in the system at 2.0, that trails renewable

energy technologies linked to energy storage systems (Korea Energy Agency).

The Third Energy Master Plan, which lays out South Korea's long-term energy policy goals and potential implementation steps, also supports the transition to a hydrogen-based economy. It has set a target of generating 30–35% of South Korea's power through renewables by 2040. This is up from a prior target of 20% in 2030. It also reinforces the move toward eco-friendly vehicles and the prominence of hydrogen in South Korea's plans to transition to renewable energy (Ministry of Industry, Trade, and Energy 2019).

There are also efforts to promote the usage of hydrogen on the local level. The city of Ulsan, where Hyundai Motors has a strong presence, has set a goal of becoming a leading center for the hydrogen economy by tapping into the abundant hydrogen byproduct produced by its chemical industry. By 2030, it is aiming to have 15% of passenger vehicles and 40% of city buses run on hydrogen fuel cells. These vehicles would be supported by 60 refueling stations (Cho 2018).

## Private sector initiatives

The Hyundai Motors Group and its affiliates are the most prominent chaebol working to develop hydrogen as a fuel source. In 2013, Hyundai launched the first mass produced FCEV, the Tucson iX35, and is working to develop the technology as a major part of its strategy.

In 2018, Hyundai announced its "FCEV Vision 2030." Under the 2030 vision, Hyundai Motor Group and its suppliers plan to invest 7.6 trillion won (\$6.7 billion) in the expansion of facilities and R&D with the goal of producing 700,000 fuel cell systems annually by 2030. FCEVs would account for 500,000 of the fuel cells, while the remainder would be for rolling stocks, drones, vessels, and forklifts. In addition to the expanded production of fuel cell-enabled equipment, these investments are expected to create 51,000 jobs (Hyundai Motor Group 2018).

After trailing Toyota in recent years, Hyundai is now the world's largest seller of hydrogen vehicles. With its Nexo SUV currently available in markets such as South Korea, the USA, and the European Union, Hyundai sold 4987 Nexo FCEVs globally, including 4194 of units in South Korea (Kane 2020b). As part of its 2030 plan, it hopes to expand sales to 40,000 FCEVs in 2022, 130,000 in 2025, and 500,000 by 2030.

At annual sales of 100,000 units, Hyundai estimates that FCEVs will be price competitive with electric vehicles and that strengthened environmental regulations will make fuel cell, electric, and internal combustion engine vehicles equal in total cost.

At a meeting of the Hydrogen Council in 2020, Council Co-chairman Chung Euisun, Executive Vice Chairman of

the Hyundai Motor Group, suggested that there are three necessities for realizing the adoption of hydrogen as a fuel source more broadly by society—improving safety, reducing costs through the development of related technologies, and increasing the public awareness of hydrogen's merits as an alternative energy source (Yonhap News Agency 2020a, b, c, d, e, f).

But to help popularize the technology, Hyundai is looking to sell hydrogen fuel systems to its competitors and not remain dependent on the sale of its own vehicles (White and Song 2019).

There is the potential for economic synergies between the production of passenger and commercial vehicles, but Hyundai's plans for commercial vehicles are less developed. In 2019, it formed a joint venture, Hyundai Hydrogen Mobility, with H2 Energy in Switzerland to provide 1600 heavy duty trucks for leasing by 2025. While the venture is currently focused on Switzerland, the expectation in time is to expand to other parts of Europe (Hyundai Motor Group 2019). Hyundai has also announced that it will begin producing commercial vehicles at its plants in China for the local market by 2023 (Yonhap News Agency 2020a, b, c, d, e, f).

In 2020, Hyundai signed a Memorandum of Understanding with the U.S. Department of Energy to collaborate in an assessment of the viability of hydrogen vehicle technology (U.S. Department of Energy 2020). Similar to its efforts in South Korea, for Hyundai to be successful in the USA, it will need the US government or state governments to support the industry through the construction of refueling stations.

Hyundai is not alone in investing in hydrogen fuel cell technology. Doosan recently spun out its fuel cell division into a separate company to advance the division's growth and is set to complete construction on South Korea's first liquid hydrogen plant in 2021 (FuelCellWorks 2019). Doosan's Mobility Division has also developed a hydrogen fuel cell drone designed to provide deliveries in areas with poor infrastructure (Song et al. 2020).

Hanwha Energy has completed the world's first by-product hydrogen power plant, which opened in July 2020 in the Daesan Industrial Complex. The plant utilizes fuel cells produced by Doosan (Lee 2020).

South Korea's dominate steel producer, Posco, also produces both fuel cells and components for fuel cells.

The South Korean government also helped to form a special purpose corporation, HyNet, composed of 13 companies to invest 135 billion won (\$118.7 million) to construct 100 refueling stations by 2022. The consortium would continue to run the stations through 2028 (Lim and Lee 2019).

However, there is still ground that will need to be made up with the infrastructure for electric vehicles. In 2019, there were estimated 65,000 charging stations in South

Korea (Statista 2020) and Tesla alone has built 450 slow-charging stations and 32 super-charging stations (Yonhap News Agency 2020a, b, c, d, e, f).

## Additional steps South Korea can take

South Korea has put forward a comprehensive plan to create the initial infrastructure, R&D, and investment needed to seed the development of a hydrogen economy, building on a foundation of hydrogen fuel cell vehicles and test projects such as the development of hydrogen cities. However, there are additional steps it should consider.

To further encourage the adoption of hydrogen as a fuel source, South Korea could either increase the weighting for hydrogen fuel cells or include a mandatory requirement similar to the RPS' obligations for solar power. It could also consider a phase out of the sale of new combustion engine vehicles similar to France and the UK to encourage the development of vehicles that run on alternative energy sources.

South Korea's ultimate success will most likely come down to policy consistency. Nurturing hydrogen as a viable power source for the South Korean economy will require long-term support from the Korean government and industry. The current roadmap runs through 2040. However, the nature of South Korea's single-term presidency means that policies are vulnerable to being minimized or reversed by even administrations of similar political ideology.

For the moment, there seems to be cross-party support for developing hydrogen as a fuel source. But South Korea has seen prior shifts in policy emphasis. The Roh Moo-hyun administration began supporting research into hydrogen in the late 1990s, but his successor shifted the emphasis to nuclear power—an energy source that the current administration hopes to phase out. If South Korea is to be successful in creating the ecosystem necessary to develop a hydrogen economy, there will need to be policy consistency in the years ahead.

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## Affiliations

Troy Stangarone<sup>1</sup> 

<sup>1</sup> Korea Economic Institute of America, Washington, DC, USA